Winter 12-11-2017

A PILOT NURSERY STUDY OF THE MISSOURI GRAVEL BED SYSTEM ON PHYTOREMEDIATION TREE SPECIES, POPULUS DELTOIDES X POPULUS NIGRA DN34 AND PINUS NIGRA, FOR POTENTIAL GROWTH ENHANCEMENT OVER SOIL GROWN TREES

Thomas Frontera
tjfrontera@gmail.com

A PILOT NURSERY STUDY OF THE MISSOURI GRAVEL BED SYSTEM ON PHYTOREMEDIATION TREE SPECIES, *POPULUS DELTOIDES X POPULUS NIGRA* DN34 AND *PINUS NIGRA*, FOR POTENTIAL GROWTH ENHANCEMENT OVER SOIL GROWN TREES

by

Thomas John Frontera II

A thesis
submitted in partial fulfillent
of the requirements for the
Master of Science Degree
State University of New York
College of Environmental Science and Forestry
Syracuse, New York
May 2018

Department of Landscape Architecture

Approved by:
Tim Toland, Major Professor
Dr. Lee Newman, Steering Committee Member
Dr. Doug Johnston, Steering Committee Member and Department Chair
Terry Ettinger, Thesis Examiner
Dr. Jose Giner, Examining Committee Chair
S. Scott Shannon, Dean, The Graduate School

Acknowledgements

*I would like to thank my thesis committee,
Dave and Jeanne Ryan of Rare Earth Nursery without whom this thesis would not have been possible, and my family especially my father who endured my countless thesis drafts. Lastly, I dedicate this thesis to my mother Ann Marie Frontera.
Rest in Peace Mom.*

Table of Contents

List of Tables:

List of Figures*:

*Unless otherwise noted, figures by author.

Abstract:

The nursery industry has three standard root forms, bareroot (BR), balled and burlapped (B&B), and containerized, each with advantages and disadvantages. This thesis looks to discuss these advantages and disvantages in comparison to a new plant propagation method, Missouri Gravel Bed System (MGBS). Due to the regrowth of the fine roots lost during harvest, BR MBGS trees can be harvested while in full leaf giving the trees the same planting versatility as B&B and containerized trees but at much lighter weight. The larger root mass of the BR MGBS trees may improve survival and establishment and may also have a positive impact in phytoremediation. The pilot experiment, conducted as a part of this thesis, compared growth and success of BR MGBS trees to B&B trees. The results showed that the MGBS can increase root and stem growth over silt loam soil for the phyto species, *Populus deltoides x Populus nigra*.

Keywords: Missouri Gravel Bed System, Balled and Burlapped, Bareroot, Bare root, Containerized, Phytoremediation, Hybrid poplar (*Populus deltoides x Populus nigra*), Austrian pine (*Pinus nigra*)

Chapter 1: Introduction

This pilot study investigates nursery bedding practices relative to growth and mortality in plant propagation. The focus is on comparing two different types of bedding media to the initial growth and mortality of Austrian pine (*Pinus nigra*) and hybrid poplar (*Populus deltoides x Populus nigra* DN34 ‘Imperial Carolina’). The purpose is to determine if the Missouri gravel bed system (MGBS) provides better in-nursery survival rates and increased root mass than an in-soil control for the selected tree species. This thesis looks to connect existing knowledge, introduce new ways of thinking, and provide a foundation for future larger and longer studies.

1.1: Background and Literature Review

1.1.1: Root Forms Available in the Nursery Industry

The nursery industry provides plants used in a number of different landscape applications, both large and small. The production and delivery of these plants are governed by several practices and techniques that have evolved over time into nursery production standards. Each of these practices has advantages and disadvantages in production, harvesting, shipping, planting, and the short and long term growth of plants. Of particular interest is the production of trees. Given their generally larger size, trees are extremely beneficial in site development as they create more immediate impacts in the landscape; however their increased size also comes with downsides such as weight and cost. One way to mitigate these downsides is by specifying the best tree root form from a holistic perspective. The three standard root forms available in the tree nursery industry are bareroot (BR), balled and burlapped (B&B), and containerized.

In all three of these practices the trees are propagated vegetatively or by seed, sometimes in a greenhouse. These saplings are then transplanted as bareroot stock or plugs in the first step of the respective tree growing method. All three production methods, even containerized, can involve the planting of the bareroot stock or plugs in a field at a spacing to allow for multiple years of growth. From this point forth the similarities in the production methods cease and each root form takes a different journey to the final product.

In B&B production, trees are grown in-ground for a period of time, typically in large fields. They are then usually harvested by a tree spade; however, some growers will harvest by hand. Harvesting with a tree spade is very time efficient but energy intensive (Ettinger, 2018) while harvesting by hand is very energy efficient but labor-intensive. In B&B the soil and roots are held together by wrapping them in burlap and a wire basket, forming a root ball. With adequate watering these trees can stay in this form for many months. Soil is kept permanently around the roots and is shipped with the plant. This soil adds a tremendous amount of weight to the plant making shipping and handling expensive and makes planting more difficult once on site. A study of northern nursery production systems done by Neal et al. (2014) found that on average the soil and soil water accounted for almost 92% of the total weight of each B&B tree, with only 7% being the actual tree itself.

According to Fair (2014) B&B plants are typically preferred by consumers because they have “a wide range of available species” and are available in larger sizes which give them the ability to create an “instant landscape”. However, when compared to containerized and BR plants, B&B plants have slower establishment times and higher initial and long-term costs.

Several issues have been identified with the B&B production process, such as j-rooting and root flare mounding. Mechanization throughout the B&B process makes it less labor intensive and more time efficient however this speed comes with detrimental consequences. J-rooting occurs when the bareroot stock or plugs are lined out in the production field with a mechanized tree planter and the saplings are inadvertently dragged slightly by the machine. This sweeps the roots back and as a result the roots only grow on one side of the tree. There are a few causes of root flare mounding. One cause occurs when the trees are growing in the field, cultivator machines are regularly going up and down the tree rows to manage the weeds. This process can push soil over the root flare or the stem/root interface (Ettinger, 2018). Also, during the harvesting process the tree spade can push soil over the root flare. If this mounded soil is not removed from the root flare the tree can be planted too deep, potentially causing it to suffer and likely lead to an untimely demise (Ahern, 2011).

B&B trees have many other downsides beyond those described above, depending on which view point is taken. For landscape contractors the weight of B&B plants makes them very difficult to work with and even dangerous. From an invasive ecology perspective transporting trees with soil allows undesirables such as weeds, insects, and fungi to hitch a ride within the soil (Liebhold et al., 2012). From the grower's vantage point the harvesting process removes soil from where the trees are grown often leaving the sites depleted of essential topsoil. Neal et al. (2014) found that the B&B production process can remove as much as 65-80 tons/acre per year of soil. As time goes on the removal of topsoil can cause a diminishing return in investment due to the added amendments (fertilizer, etc.) that will be needed to keep the exhausted soil productive (Magley & Struve, 1983) not to mention the environmental costs associated with this.

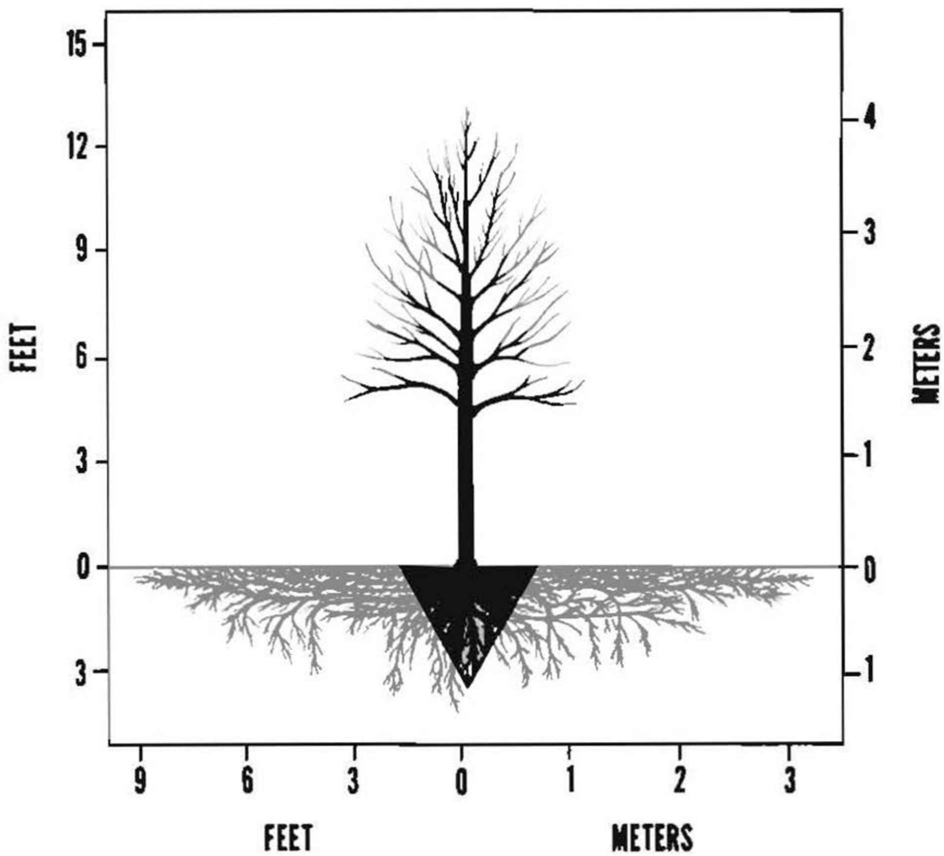

Figure 1: B&B Root Loss
This diagram visually depicts the potential root loss that occurs in the B&B process. Image source: Magley & Struve, 1983.

From the standpoint of root system health the main disadvantage of B&B material is the loss of a majority of the root system during harvest. Fair (2014) found this loss to be up to 75% of the total root system while Magley & Struve (1983) found that the root loss was as high as 98% (Figure 1). This loss of root mass is of noteworthy concern as the tree subsequently spends a signficant amount of its energy restoring its root system during the early years after planting. Also according to Magley & Struve (1983) this root restoration period can result in 3-6 years of reduced growth. Some growers attempt to mitigate the transplant shock by pruning the roots on a regular basis to prepare the trees for harvesting (Watson, 1986) however in many cases this is still inadequate. According to Watson (1985) it would take a 4” caliper[1] B&B tree five years to regrow its original root system, while it would take over ten years for a 10” caliper B&B tree to do the same. Watson also states that after 13 years “it is possible for the original 4-inch tree to be larger than the 10-inch caliper tree” (Figure 2).

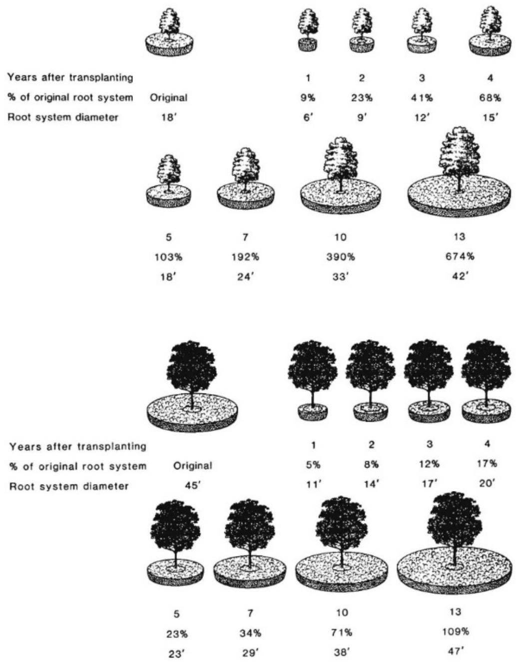

Figure 2: Root/Shoot Ratio
This diagram from Watson (1985) shows how a younger 4” caliper tree can surpass a larger 10” caliper tree in just 13 years highlighting the importance of the root/shoot ratio.

Watson’s findings suggest that larger trees suffer greatly in the B&B process and that a higher ratio of below ground to above ground biomass makes for a more successful tree. As stated previously, one reason consumers prefer B&B trees is because of their larger available sizes. Therefore, consumers are spending more money purchasing larger trees that will most likely experience sluggish initial growth due to their lower root/shoot ratios.

Halka Nurseries of New Jersey is one of the leading suppliers of large specimen trees. They sell trees ranging from 3 to 20 inch caliper and provide for some of the most high-profile

[1] Caliper is the diameter of the trunk, measured 6” from the ground.

projects in the country, including the World War II Memorial (Washington, D.C.), the Statue of Liberty (NYC), Battery Park (NYC), Ellis Island (NYC), the U.S. Capitol Building (Washington, D.C.), and the 9/11 Memorial (NYC) but their largest sector is high-end residential. Their 12-step process starts with planting some 25,000 whips per year and allowing them to grow for 10 plus years. When the trees get to three inches in caliper some trees are thinned to be sold and allow room for the other trees to grow much larger using Halka Nursery's specialized harvesting method. When the trees are ready to harvest they are carefully balled and burlapped by craftsmen and lifted out of the ground with specialized heavy-lift equipment. At this point some of the harvested trees have been in the ground for decades and weigh as much as 40 tons. The immense weight of some of the trees allows for only one tree to be shipped per semi flatbed trailer (Halka, 2017). In the case of the 9/11 memorial over 400 swamp white oak trees (*Quercus bicolor*) were transported almost 60 miles, each requiring its own truck and weighing 18,000 pounds (Randall, 2013). Based upon the Neal et al. (2014) findings on the proportion of soil weight to tree weight it could be suggested that of each 18,000-pound truckload, over 16,000 pounds was just soil.

Containerized trees are typically propagated from plugs, cuttings, or seeds in pots with a light weight growing medium and are moved to larger containers as they grow. The main advantages of container-grown trees are the lighter weight of the soilless medium (usually pine bark and sand) and that much of the root systems are held intact throughout growth which limits transplant shock at planting (Fair, 2014). Neal et al. (2014) found that containerized trees have roughly 30% more total roots and roughly 22% more fine roots by dry weight than B&B trees. Some containerized plants are field-grown then harvested with a tree spade, like B&B, and placed in containers. This field-grown containerized tree process suffers the same root loss and topsoil depletion as the B&B process due to the harvesting similarities.

The main drawbacks to containerized trees include the potential for the roots to become pot bound and the faster rate in which the soilless medium dries out in the nursery (Fair, 2014). A plant is root-bound when the roots outgrow the vessel and begin to circle along the container wall. “These circling roots will impede future root growth and development of the plant” and are difficult to see because view of the roots is blocked by the container (Fair, 2014). To discourage plants from becoming pot bound some containers are specially designed to automatically root prune the plant using air exposure while allowing the roots to stay intact. Trees can survive for a period of time with pot-bound roots, however, they will most likely experience lethargic growth causing them to take longer to establish. Since the roots usually continue the same circular growth path established in the pot they will likely fail in the long term due to the development of girdling roots (Whitcomb, 2014).

The traditional BR method calls for the complete removal of soil from around the root system of field-grown trees at harvest. The main advantages of BR trees are their lighter weight and their more numerous root systems when compared to B&B and containerized trees. Watson and Himelick (1997) found that during conventional B&B harvesting 90% of the root system can be left in the soil while Haug (1996) found that trees dug bareroot had 200% more roots when compared to trees dug B&B. Due to their lighter weight they are easier and cheaper to handle during harvesting, transporting, and planting, which results in a 33%-50% cost reduction versus B&B trees (Anella et al., 2008). They are so light that they can often be carried by hand once at the job site. In a study done by Anella et al. (2008) “a crew of three people planted all the bare-root trees using a small tractor and a box blade in less time than a crew of five people working with a front-end loader could unload the B&B trees from the trailer”. Also, since there is no soil transported with the trees the spread of undesirable weeds is greatly reduced if not eliminated.

Additionally, because there is no soil to block the view of the root flare the trees have a lower likelihood of being planted too deep, a common problem with B&B trees.

Figure 3: BR Harvesting
Even though the BR harvesting process retains much more roots than the B&B process it is still disruptive to the fibrous roots making harvested BR trees quite delicate. The process can sometimes leave the saplings sparse of roots. Image source: http://www.groworganic.com/organic-gardening/videos/the-journey-of-a-bare-root-tree.

Unfortunately, there are still drawbacks to BR trees. There is still root loss due to the fairly destructive harvesting process disturbing the delicate and vital fibrous roots (Figure 3). Harvested BR trees can be quite frail due to the damage to the roots and the absence of soil to protect them. To preserve the plants, they are typically dipped in a hydrogel to prevent desiccation and must be kept cool and planted soon after harvesting. Even with the hydrogel the BR trees are still prone to drying out. The high risk of desiccation limits BR trees' planting window to when dormancy occurs in fall and winter. Furthermore, traditional BR is not recommended for caliper size trees greater than 2" because of transplant difficulties (Buckstrup & Bassuk, 2009). For this reason, a consumer who is looking for the "instant landscape", as mentioned before, will tend to seek out other root forms with larger caliper sizes.

Horticulturalists have been trying to develop a tree production method that combines the strengths of all the root forms and minimizes the weaknesses. Currently B&B is the most popular of the root forms due to its relative ease of harvest, long seasonal planting window, and reasonably high success rate but as stated above the weight and loss of root volume can be issues for planting and establishment. Containerized trees are the next most popular option with many of the same benefits of B&B but with lighter total weights and more roots retained. However circling roots can be a major issue for this root form. BR trees are the lightest of the options and have the highest retention of roots during harvest however they are extremely prone to drying out even when preventative measures are taken. The Missouri Gravel Bed System (MGBS) is a relatively new plant option that has shown the potential to be superior to the traditional root forms because it has many of the same benefits with much fewer drawbacks.

1.1.2 Missouri Gravel Bed System (MGBS)

The Missouri Gravel Bed System (MGBS) was developed in the 1980s by Dr. Chris Starbuck of the University of Missouri, as a means of addressing the issues created by traditional nursery techniques. The system holds BR trees in large beds for several months in a mixture of 10% masonry sand and 90% 3/8” round stone (pea gravel) irrigated with fertilized water. The mixture is about 18”-24” deep, lined with permeable or impermeable geotextile fabric held in place with framing (Figure 4).

When the system was first developed, it was intended to be a holding method to extend the planting season of BR plants by re-growing the fibrous roots lost during harvest. Due to the regrowth of the fine roots (Figure 5) BR MBGS trees can be harvested while in full leaf giving the trees the same planting versatility as B&B and containerized trees. This is a preferred approach to planting because as previously stated BR trees have considerably more roots and weigh much less than their B&B counterparts. A two-inch caliper tree would traditionally weigh in at over 200 pounds as a B&B tree but as a BR MGBS tree would weigh less than 40 pounds (Ryan, 2015).

Figure 4: MGBS Bed
This image shows the typical gravel bed construction at Rare Earth Nursery. These beds were under construction during the experiment.

While the technique holds much promise, there are a limited number of species utilizing this method because of the lack of widespread studies. This study seeks to identify previously untested plant species for propagation in a MGBS and compare their growth to a silt loam soil control group.

Figure 5: MGBS Fine Roots
This image shows the incredible root structure that develops when the BR stock trees are grown in the MGBS. This tree, harvested in full leaf, awaits delivery to the client.

1.1.3: Rational for Study Plant Species Selection

While having a more robust root system benefits any plant at time of installation, the researcher for this project was interested in identifying species for the specific application of trees for phytoremediation projects. Phytoremediation is the use of plants to clean and/or stabilize pollutants in soil, and the interaction between roots and soil is a critical component of the phyto processes. Through a large amount of background research into phytoremediation the researcher concluded:

> *More plant roots provide the opportunity for more root interaction with the soil, a larger root surface area increases the likelihood that the mechanisms of phytoremediation can be engaged, thereby enhancing pollutant cleanup. (Aken et al., 2003; Gatliff, 1994; Hollander et al., 2010; Kennen & Kirkwood, 2015; Leigh et al., 2002; Mackova et al., 2006; McCutcheon & Schnoor, 2003; Meggo & Schnoor, 2013; Meharg and Cairney, 2000; Rajakaruna et al., 2006 and Schroder, 2011).*

Therefore, the guiding hypothesis for this project became those plants grown in MGBS would have a larger root mass and as a result potentially be able to establish on a site sooner and maybe even bring about faster phytoremediation results.

During background research, it was identified that *Pinus nigra* and *Populus deltoides x Populus nigra* DN34 would be noteworthy species to test using the MGBS. *P. deltoides x P. nigra* is a well-known phreatophytic[2] tree that has been extensively studied for its phytoremediation value. *Pinus nigra* is a very hardy evergreen tree that has shown promise in the remediation of a major class of contaminants, PCBs (Leigh et al., 2006). Weeping willow (*Salix*

2 Phreatophytes are very deep rooted and usually have at least a part of their root system constantly in touch with water. These plants send long root systems in search of water and can reach depths of up to 30 feet or more (Kennen & Kirkwood, 2015).

babylonica) was also considered because it was available for purchase from the tree supplier and like *Populus deltoides x Populus nigra* it is a phreatophytic tree. Additionally, the *Salix* genus has also been extensively studied in phytoremediation.

Salix and *Populus* were often used in similar ways in phytoremediation however with *Populus* holding a clear advantage (Labrecque & Teodorescu, 2004), (Zalesny et al., 2007). For this reason and since phytoremediation studies specifically using *Salix babylonica* could not be found, *S. babylonica was* omitted from this project. As stated above *Pinus nigra* is a promising but relatively underutilized tree species in phytoremediation that could be more intensely used in the future with further study. As an evergreen tree, it also provides different opportunities for site design than do the other phyto species, which tend to be deciduous.

To confirm whether the MGBS had been tested on Austrian pine, hybrid poplar, or weeping willow, Dr. Chris Starbuck the inventor of the system, was contacted. When asked if he or anyone he knew tested the system on these three tree species he stated that he had not tested the system on willows or poplars but did test pitch x loblolly pine (*Pinus rigida x taeda*) hybrids however not *Pinus nigra* (2015). Dr. Starbuck then suggested contacting Dr. Gary Johnson, of the University of Minnesota. Dr. Johnson has studied and experimented heavily on the MGBS. When Dr. Johnson was asked the same question, he stated he had tried some poplars with success, *Populus tremuloides* and *Populus grandidentata*, but not *P. deltoides x P. nigra.* He also tried ponderosa pine (*Pinus ponderosa*), jack pine (*Pinus banksiana*), and red pine (*Pinus resinosa*) however never Austrian pine (2015).

Chapter 2: Materials and Methods

2.1: Experiment Set-Up

The project intended to compare the growth of the chosen species in a typical MGBS setup to those grown in a silt loam soil. The experiment consisted of 30 BR stock saplings, 15 *Populus deltoides x Populus nigra* DN34 ‘Imperial Carolina’ and 15 *Pinus nigra*, purchased from the Arbor Day Foundation. Both species had little to no roots or branches present at planting. The poplars were essentially 2-3 foot whips and the pines were single stemmed saplings with the needles emerging directly from an 8-12 inch main stem.

Within each species group, saplings were randomly divided into two groups. The groups were named Missouri gravel bed system (MGBS) group and soil with fertilizer (Soil W/ Fert.) group. Within the MGBS group the plants were numbered 1 through 5 and labeled via plastic flags that identified the tree group and number (Figure 6). The same was done to the Soil W/ Fert. group. At the start of the experiment there was a Soil W/O Fert. group however due to irrigation constraints, discussed below, it was merged with the Soil W/ Fert. group.

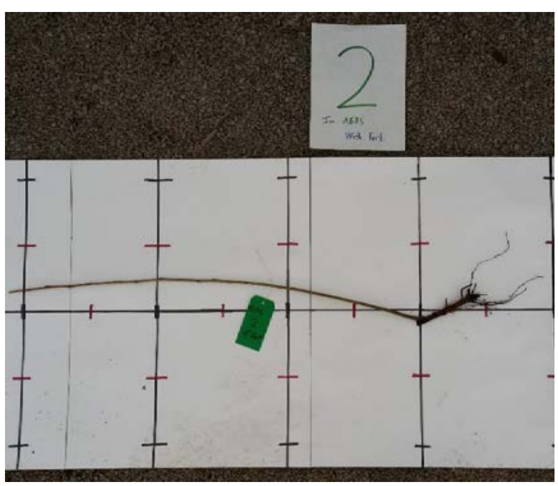

Figure 6: Pre-Experiment Image
This image shows how the trees were labeled before planting on May 13th, 2015. The red markers are in 6” increments while the black markers are in 12” increments.

The research plots were established at Rare Earth Nursery of Cazenovia, NY, approximately 15 miles southeast of Syracuse, NY. It is one of the only Missouri Gravel Bed System nurseries in the state of New York. Dave and Jeanne Ryan, the owners of Rare Earth Nursery, provided most of what was necessary for the testing. This included 300 square feet of gravel bed space, 600 square feet of planting area for the soil group, an irrigation system, hand tools, and a MGBS harvester.

Figure 7: MGBS Test Bed
This image was taken soon after planting in the MGBS beds on May 13th, 2015. The poplars were branchless therefore they had no leaves to start the experiment. The pines were 8”-12” tall with a main stem and no secondary branches.

The MGBS beds were 18” deep consisting of a mixture of sand and pea gravel (Figure 7), as described previously. The soil for the in-ground beds was classified as a silt loam with the soil texture analysis yielding a result of 34.4% sand, 50% silt, and 15.6% clay (Figure 8). After planting, the soil beds were covered with 2-3 inches of wood chips to hold moisture and control weeds. Wood chips were not applied to the MGBS group because moisture retention and weed prevention are of little to no concern with the MGBS (Figure 9).

Figure 8: Soil
This is an image of the silt loam soil present in the soil beds. The soil texture analysis yielded a result of 34.4% sand, 50% silt, and 15.6% clay. The soil did not have any measurable organic matter present.

At the start of the experiment all groups were irrigated via drip irrigation, with the Soil W/O Fert.group having its own line to bypass the fertilizer. Irrigation was challenged by several things including, but not limited to, the solar-powered system used at Rare Earth Nursery. While working well when the sun was shining, the system became less reliable when the batteries were depleted in overcast conditions. The gravel bed was watered 20-40 minutes per day depending on time of year and weather conditions with 0.9 gph/ft drip-lines at 10 psi. The soil groups were originally watered at the same frequency and duration via four 1.1 GPH dripheads but this was discontinued shortly after planting. Dave Ryan, consulting nurseryman for the study with decades of plant care experience, decided that the original soil group irrigation configuration would over water the trees. As a result, Mr. Ryan hand watered both soil groups once every four days, depending on the weather, with roughly 10 gallons of fertilized water. It was Mr. Ryan's opinion that this irrigation regime was "the amount necessary for healthy growth" (2015). The fertilizer and its concentration was the same as the MGBS group. Since the goal of the study was to compare the growth of MGBS grown trees to conventionally B&B grown trees and that a non-fertlizer group did not acurately mimic typical tree production, merging the two soil groups into one fertilizer soil group seemed to make the most sense.

Figure 9: Soil W/ Fert. Test Bed
This image shows the soil bed plot. The saplings were planted on May 13th, 2015. Soon after planting the bed was covered with 2-3 inches of wood chips. The poplars were placed behind the pines to limit shading of the pines.

Table 1: Fertilizers

Nutrient Compounds	Plantex Solutions pH Reducer fertilizer	Jack's Professional Acid fertilizer.
Total nitrogen (N)	18% (9.5% Ammoniacal Nitrogen, 8.5% Nitrate Nitrogen)	21% (11.47% Ammoniacal Nitrogen, 9.53% Nitrate Nitrogen)
Available Phosphate (P_2O_5)	9%	7%
Soluble Potash (K_2O)	18%	7%
Sulfur (S)	0%	15%
Magnesium (Mg)	0%	0.7% water soluble magnesium (Mg)
Boron (B)	0.02%	0.0068%
Copper (Cu)	0.05% chelated copper	0.0036% chelated copper
Iron (Fe)	0.25% chelated iron	0.15% chelated iron
Manganese (Mn)	0.075% chelated manganese	0.025% chelated manganese
Molybdenum (Mo)	0.015%	0.0009%
Zinc (Zn)	0.075 chelated zinc	0.0025% chelated zinc

Rare Earth Nursery uses a high acid fertilizer to offset the alkaline conditions due to the limestone in the gravel and the high pH (8-8.2) of the well water. Feeding for the gravel bed trees began in May at 25 ppm (of Nitrogen) and was increased to 50 ppm in June and July. Then in August and September the concentration was dropped back down to 25 ppm “to allow any new growth to harden off for the winter”. This fertilizer regime is on the lower end of the 50ppm-100ppm spectrum recommended by the fertilizer companies. Rare Earth Nursery alternates between Jack's Professional Acid fertilizer with 21% nitrogen, 7% phosphorus, & 7% potassium and Plantex Solutions pH Reducer fertilizer with 18% nitrogen, 9% phosphorus, & 18% potassium (Table 1). As shown above and in the table each of these fertilizers have differing potassium levels to cover the needs of multiple species, however these fertilizers also have differing levels of micro elements. These micro elements are not quite as important as the macro elements listed above but still greatly benefit plant health and vigor. “The Missouri Gravel Bed system was meant to be a holding system for bare root stock, but I'm using it as a growing system. As such, it's basically hydroponics" (Ryan, 2015).

2.2: Measuring Success of the Trees

For the purposes of this study, success is defined as the vigorous growth of both root systems and above ground plant parts. Plant growth in the study was measured using various qualitative and quantitative methods. Prior to planting, the study trees were photographed on a measured background and weighed using a food scale. These images were then brought into an AutoCAD drawing and scaled to actual size using the measured background. Using AutoCAD commands, the hybrid poplar root area and stem length and the Austrian pine root area, canopy area, and stem lengths were measured. These procedures were repeated following harvest (Figures 12-13). Using the pre- and post- wet weights, the percent wet weight growth was calculated.

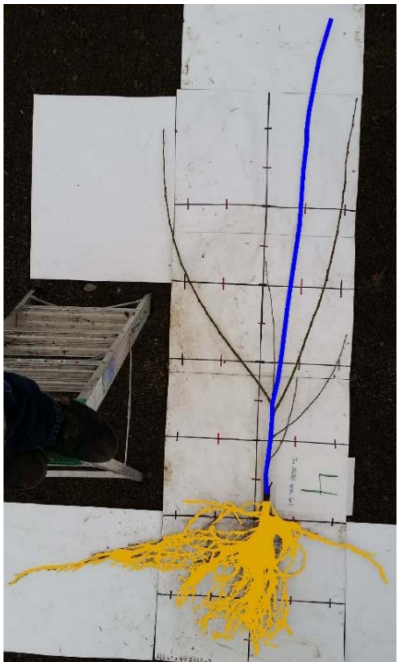

Figure 10: AutoCAD Analysis of Poplar
This image shows how AutoCAD was utilized to measure the poplars post experiment. The blue line shows how the main stem of this tree was measured. The brown hatch delineates the extent of the root system for the B&B root loss analysis.

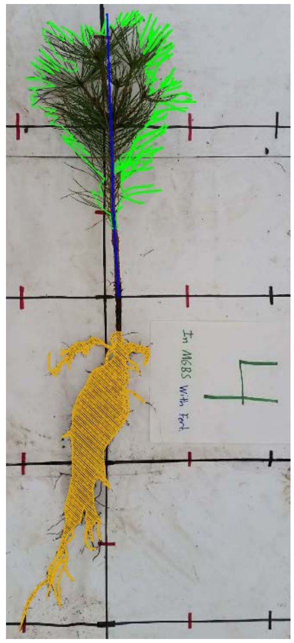

Figure 11: AutoCAD Analysis of Pine
This image shows how AutoCAD was utilized to measure the pines post experiment. The blue line shows how the main stem of this tree was measured. The green outline shows how the canopy surface area was measured. The brown hatch delineates the extent of the root system for the B&B root loss analysis. However due to the high mortality rate within the pine group no analysis was able to be done.

Figure 12: Surface Area Per Gram
To find the surface area of the wet leaves for the poplars the leaves were weighed in grams. To find an average square inch per gram value leaves from four of the trees were cut into one square inch squares and weighed. After weighing the squares, they were counted to find square inches per gram. The trees measured for this were MGBS HP#2, MGBS HP#4, Soil W/ Fert. HP#3, and Soil W/ Fert. HP#7.

In order to analyze leaf growth for the hybrid poplars, the leaves were carefully cut and their petioles removed right before leaf senescence in the fall. To find the surface area of the wet leaves for the poplars the leaves were weighed in grams. (Figure 14) To account for early leaf drop the researcher monitored the study beds on a weekly basis. Leaf harvest was held off until the first sign of yellowing leaves along with any observations of leaves likely dropped from the study trees in an attempt to give the trees as much time as possible to grow (Figure 15). Right after harvest the leaves and petioles were weighed for wet weight separately in order to carry out the leaf surface area analysis. The leaves and petioles were then dried and weighed again in order to find the percent growth by dry leaf weight and dry petiole weight.

Figure 13: Poplar Leaf Harvest
This image shows how the poplar leaves were harvested on October 29th, 2015. The leaves and petioles were bagged separately to carry out the analysis.

Figure 14: Taylor Digital Food Scale
This is the Taylor Digital food scale utilized for the field portions of the experiment. This image shows the scale being used to measure the wet weight of MGBS AP#1 prior to the experiment.

To measure the wet weight of the BR stock saplings the specimens were weighed on May 13th, 2015 right before planting using a Taylor digital food scale (Figure 16). The trees were seemingly healthy and free of soil at time of planting with little to no roots. The saplings were harvested October 29th, 2015 right before leaf change of the poplars. The MGBS trees were harvested using the Rare-Earth Nursery MGBS harvester (Figure 17) which took less than 10 minutes to complete.

The soil group trees were a very different story. The trees were painstakingly harvested by carefully loosening the soil to gradually pull the trees out of the ground (Figure 18). Then the soil was washed off the roots. This was a very long process, which took many hours to complete, because of the extensive root systems of the poplars. The soil trees were harvested this way instead of typical B&B harvesting methods, as the researcher sought to compare total root growth of the entire root systems along with the root loss that would have occurred if they were harvested with a tree spade. To determine root loss from the B&B method AutoCAD was used. Once a root ball size was determined for a given specimen using the American Standard for Nursery Stock (2014) a root ball shape was drawn to scale and overlaid on top of the scaled specimen images within the AutoCAD measurement file (Figure 19).

Figure 15: MGBS Harvester
This is the Rare Earth Nursery MGBS harvester with custom built attachment.

Figure 16: Soil Group Harvesting
This image shows how a hose was utilized to careful extract the soil group trees from the beds. The trees were removed by slowly by hand washing away soil from the roots with a jet nozzle and loosening the soil so that the trees could be lifted out.

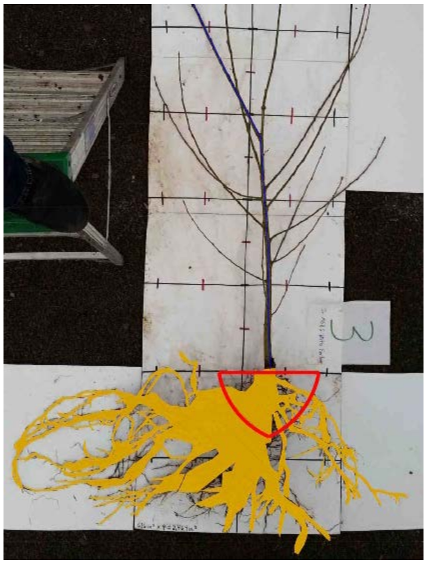

Figure 17: Measuring B&B Root Loss
This image shows how AutoCAD was utilized to find the potential B&B root loss. The minimum size root ball per the American Standard for Nursery Stock for a ¾" caliper tree was drawn into the AutoCAD file. All of the roots outside the red root ball shape were considered to be lost during harvest.

After harvest all trees were shaken gently to remove any excess water clinging to the roots or stems, then weighed and photographed on the measured background. To measure the dry weights of the saplings the samples were loaded in batches and dried for 3 days at 60 degrees Celsius (Figure 20).

Figure 18: Plant Material Drying
After all the saplings were harvested and wet weight weighed they were loading into the oven in batches and dried. The plant material was dried at 60 degrees Celsius for 3 days to obtain dry weight values.

2.3: Study and Research Questions

1. What previously untested species can be identified, and will they survive in the Missouri Gravel Bed System (MGBS)?
2. Will the species chosen and grown in the MGBS outperform those grown in the soil group?
    a. Will the MGBS have a larger and more robust root system than the soil group?
    b. Will the MGBS have a higher root/shoot ratio than the soil group?
3. What percentage of roots would have been lost if all trees were harvested B&B?
4. Does the MGBS have the potential to enhance phytoremediation?

Chapter 3: Results

3.1: Statistical Analysis:

To carry out the statistical analysis Microsoft Excel was utilized. First the normality was tested, using Anderson-Darling test, to determine if the data followed a normal distribution:

Null hypothesis (H_o): The variable from which the sample was extracted follows a Normal Distribution.

Alternative hypothesis (H_a): The variable from which the sample was extracted does not follow a Normal Distribution.

If the data was found to have a normal distribution, then an unpaired right-tailed two sample t-Test was conducted. Variable 1 (μ_1) was the MGBS group and Variable 2 (μ_2) was the Soil W/ Fert. group. If the t stat value was greater than the t critical value and the p-value was less than the alpha level of 0.05 then it was considered that the data showed enough evidence to support the claim that the MGBS increased growth over the Soil W/ Fert. group.

The following figures show the results of the statistical analysis. The figures only show the portions of the experiment that were considered statistical significant by the Anderson-Darling test and the unpaired right-tailed two sample t-Test. Each figure is discussed in detail subsequent sections.

3.2: *Populus nigra x Populus deltoides* (Hybrid Poplar)

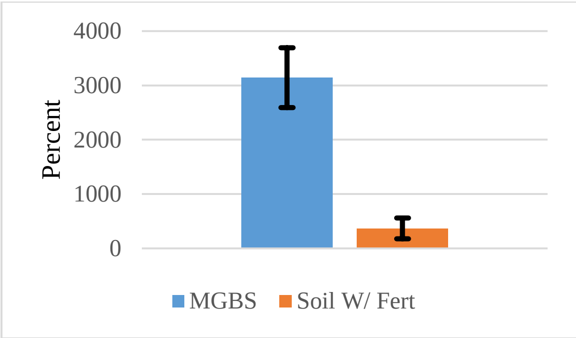

Figure 19: Percent Growth by Total Wet Weight

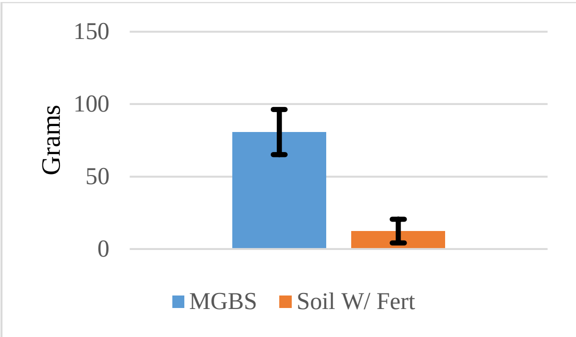

Figure 20: Leaf and Petiole Growth by Dry Weight

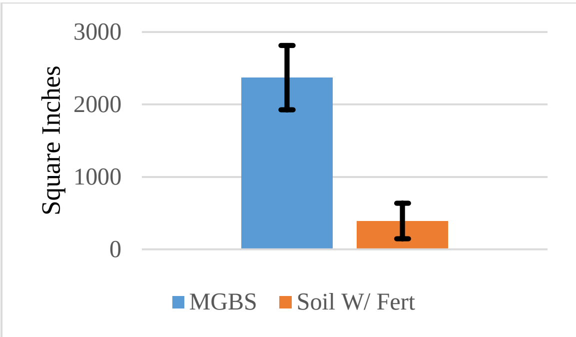

Figure 21: Leaf Surface Area by Wet Weight

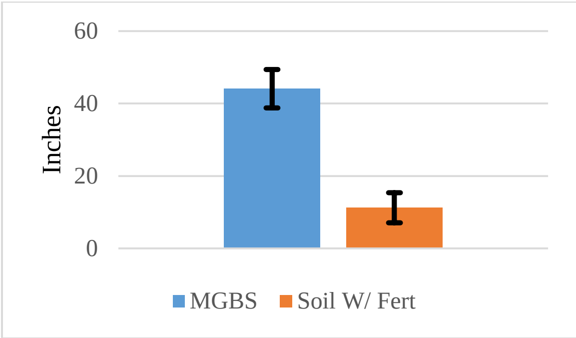

Figure 22: Average Branch Length of 3 Longest Branches

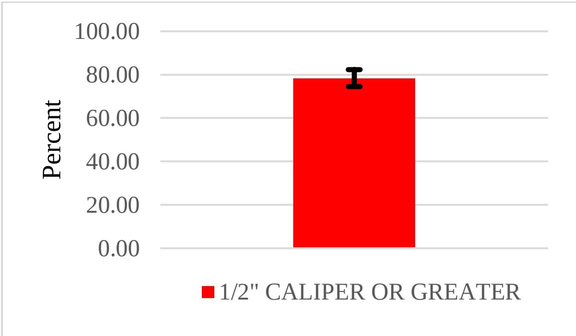

Figure 23: B&B Process Potential Root Loss

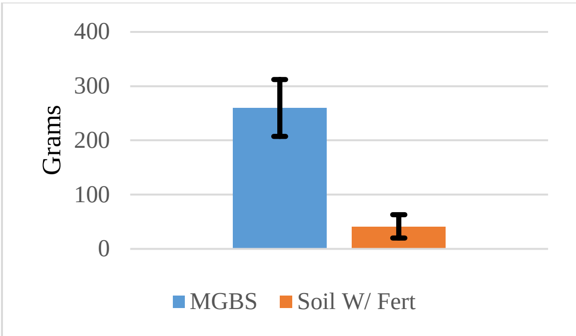

Figure 24: Root Growth by Dry Weight

3.2.1: Average Percent Growth by Total Wet Weight Analysis

According to the Anderson-Darling test, the data from the MGBS group and Soil W/ Fert. group were Normally Distributed. The test yielded a p-value of 0.057 for the MGBS group and a p-value of 0.229 for the Soil W/ Fert. group. Both of which are greater than significant level alpha of 0.05 therefore one cannot reject the null hypothesis H_o.

The unpaired right-tailed two sample t-Test was set up as follows:

Null hypothesis (H_o): There is no difference in average percent growth by total wet weight between the groups. $H_o: \mu_1 = \mu_2$

Alternative hypothesis (H_a): The MGBS group had a greater average percent growth by total wet weight than the Soil W/ Fert. group. $H_a: \mu_1 > \mu_2$

Table 2: Percent Growth by Total Wet Weight Statistical Information

	MGBS	Soil W/ Fert.
Mean	3142.27	368.02
Variance	905741.66	184050.26
Observations	3.00	5.00
Hypothesized Mean Difference	0.00	
df	2.00	
t Stat	4.77	
P(<=t) one-tail	0.02	
t Critical one-tail	2.92	
Standard Error	549.47	191.86
Median	2593.70	200
Standard Deviation	951.70	429.01
Range	1649.30	1028.70
Minimum	2591.90	22.50
Maximum	4241.20	1051.20

Since the t stat value is greater than the t critical value and the p-value is less than 0.05 one should reject null hypothesis. At the 0.05 alpha level, the data shows that there is enough evidence to support the claim that the MGBS increased average percent growth by wet weight over the Soil W/ Fert. group. According the statistical analysis the MGBS group grew over 2,000% more on average than the Soil W/ Fert. group even when standard error for both groups is considered. Refer to Figure 21 for the graphical depiction of this data.

3.2.2: Average Leaf and Petiole Growth by Dry Weight Analysis

According to the Anderson-Darling test, the data from the MGBS group and Soil W/ Fert. group were Normally Distributed. The test yielded a p-value of 0.603 for the MGBS group and a p-value of 0.054 for the Soil W/ Fert. group. Both of which are greater than significant level alpha of 0.05 therefore one cannot reject the null hypothesis H_o.

The unpaired right-tailed two sample t-Test was set up as follows:

Null hypothesis (H_o): There is no difference in average leaf and petiole growth by dry weight between the groups. $H_o: \mu_1 = \mu_2$

Alternative hypothesis (H_a): The MGBS group had a greater average leaf and petiole growth by dry weight than the Soil W/ Fert. group. $H_a: \mu_1 > \mu_2$

Table 3: Leaf and Petiole Growth by Dry Weight Statistical Information

	MGBS	Soil W/ Fert.
Mean (Grams)	80.70	12.41
Variance	722.09	339.15
Observations	3.00	5.00
Hypothesized Mean Difference	0.00	
df	3.00	
t Stat	3.89	
P(<=t) one-tail	0.02	
t Critical one-tail	2.35	
Standard Error	15.51	8.24
Median (Grams)	82.97	1.01
Standard Deviation	26.87	18.42
Range	53.60	42.57
Minimum	52.77	0.00
Maximum	106.37	42.57

Since the t stat value is greater than the t critical value and the p-value is less than 0.05 one should reject null hypothesis. At the 0.05 alpha level, the data shows that there is enough evidence to support the claim that the MGBS increased average leaf and petiole growth by dry weight over the Soil W/ Fert. group. According the statistical analysis the MGBS group grew over 44 grams more on average than the Soil W/ Fert. group even when standard error for both groups is considered. Refer to Figure 22 for the graphical depiction of this data.

3.2.3: Average Leaf Surface Area by Wet Weight Analysis

According to the Anderson-Darling test, the data from the MGBS group and Soil W/ Fert. group were Normally Distributed. The test yielded a p-value of 0.623 for the MGBS group and a p-value of 0.079 for the Soil W/ Fert. group. Both of which are greater than significant level alpha of 0.05 therefore one cannot reject the null hypothesis H_o.

The unpaired right-tailed two sample t-Test was set up as follows:

Null hypothesis (H_o): There is no difference in average leaf area by wet weight between the groups. $H_o: \mu_1 = \mu_2$

Alternative hypothesis (H_a): The MGBS group had a greater average leaf area by wet weight than the Soil W/ Fert. group. $H_{a:}\ \mu_1 > \mu_2$

Table 4: Leaf Area (In.^{2}) by Wet Weight Statistical Information

	MGBS	Soil W/ Fert.
Mean (In.^{2})	2370.57	392.03
Variance	591093.41	302875.14
Observations	3.00	5.00
Hypothesized Mean Difference	0.00	
df	3.00	
t Stat	3.90	
P(<=t) one-tail	0.01	
t Critical one-tail	2.35	
Standard Error	443.88	246.12
Median (In.^{2})	2403.40	59.10
Standard Deviation	768.83	550.34
Range	1536.60	1270.65
Minimum	1585.85	0.00
Maximum	3122.45	1270.65

Since the t stat value is greater than the t critical value and the p-value is less than 0.05 one should reject null hypothesis. At the 0.05 alpha level, the data shows that there is enough evidence to support the claim that the MGBS increased average leaf area by wet weight over the

Soil W/ Fert. group. According the statistical analysis the MGBS group had 1,200 square inches more on average than the Soil W/ Fert. group even when standard error for both groups is considered. Refer to Figure 23 for the graphical depiction of this data.

3.2.4: Average Branch Length of 3 Longest Branches Analysis

According to the Anderson-Darling test, the data from the MGBS group and Soil W/ Fert. group were Normally Distributed. The test yielded a p-value of 0.24 for the MGBS group and a p-value of 0.102 for the Soil W/ Fert. group. Both of which are greater than significant level alpha of 0.05 therefore one cannot reject the null hypothesis H_o.

The unpaired right-tailed two sample t-Test was set up as follows:

Null hypothesis (H_o): There is no difference in average branch length of the 3 longest branches between the groups. H_o: $\mu_1 = \mu_2$

Alternative hypothesis (H_a): The MGBS group had a greater average branch length of the 3 longest branches than the Soil W/ Fert. group. $H_{a:}$ $\mu_1 > \mu_2$

Table 5: Branch Length of 3 Longest Branches Statistical Information

	MGBS	Soil W/ Fert.
Mean	44.07	11.19
Variance	83.29	85.98
Observations	3.00	5.00
Hypothesized Mean Difference	0.00	
df	4.00	
t Stat	4.90	
P(<=t) one-tail	0.004	
t Critical one-tail	2.13	
Standard Error	5.27	4.15
Median	47.58	5.38
Standard Deviation	9.13	9.27
Range	17.21	20.25
Minimum	33.71	3.13
Maximum	50.92	23.38

Since the t stat value is greater than the t critical value and the p-value is less than 0.05 one should reject null hypothesis. At the 0.05 alpha level, the data shows that there is enough evidence to support the claim that the MGBS increased average branch growth over the Soil W/ Fert. group. According the statistical analysis the branches of the MGBS group grew over 23 inches more on average than the Soil W/ Fert. group even when standard error for both groups is considered. Refer to Figure 24 for the graphical depiction of this data.

3.2.5: Average Main Stem Growth Analysis

According to the Anderson-Darling test, the data from the MGBS group and Soil W/ Fert. group were not Normally Distributed. The test did yield a p-value of 0.274 for the MGBS group, however, the Soil W/ Fert. group p-value was only 0.03. The p-value for the MGBS data is greater than significant level alpha of 0.05 however the Soil W/ Fert. group is less than significant level alpha of 0.05, therefore, one should reject the null hypothesis H_o and accept the alternative hypothesis H_a. Since the Anderson-Darling test showed that Soil W/ Fert. group data did not follow a Normal Distribution no conclusions can be drawn from the data.

3.2.6: B&B Process Potential Root Loss

For this analysis AutoCAD was used to estimate how root loss could have resulted if the trees were harvested using a tree spade. Per the American Standard for Nursery Stock the smallest caliper sizes harvested for *Populus* are ½”, $^{5}/_{8}$”, and ¾”. Five of the study trees attained a caliper of ½” or more. The three MGBS trees were closest to the ¾” caliper size while two of the Soil W/ Fert. trees were closest to the ½” caliper size. The minimum root ball diameter for a ½” caliper tree is 12” and the minimum root ball depth is 7-$^{7}/_{8}$”. The minimum root ball diameter for a ¾” caliper tree is 14” and the minimum root ball depth is 9”. Using these measurements a root ball shape was drawn into the AutoCAD measurement file and overlaid over the scaled drawing images. Any roots outside of the root ball shape were considered to be lost in the field during harvest. Refer to Figure 25 for the graphical depiction of this data.

According to the Anderson-Darling test the data from harvestable poplars was Normally Distributed because the test yielded a p-value of 0.403 which is greater than significant level alpha of 0.05 therefore one cannot reject the null hypothesis H_o.

Table 6: B&B Potential Root Loss Statistical Information

	Average Percent Root Loss
Mean	78.39
Standard Error	3.90
Median	77.49
Standard Deviation	8.71
Range	19.42
Minimum	67.80
Maximum	87.21

3.2.7: Average Root Growth by Dry Weight

According to the Anderson-Darling test, the data from the MGBS group and Soil W/ Fert. group were Normally Distributed. The test yielded a p-value of 0.614 for the MGBS group and a p-value of 0.053 for the Soil W/ Fert. group. Both of which are greater than significant level alpha of 0.05 therefore one cannot reject the null hypothesis H_o.

The unpaired right-tailed two sample t-Test was set up as follows:

Null hypothesis (H_o): There is no difference in average root growth by dry weight between the groups. H_o: $\mu_1 = \mu_2$

Alternative hypothesis (H_a): The MGBS group had a greater average root growth by dry weight than the Soil W/ Fert. group. $H_{a:}$ $\mu_1 > \mu_2$

Table 7: Root Growth by Dry Weight Statistical Information

	MGBS	Soil W/ Fert.
Mean	259.80	41.36
Variance	8189.23	2319.53
Observations	3.00	5.00
Hypothesized Mean Difference	0.00	
df	3.00	
t Stat	3.87	
P(<=t) one-tail	0.02	
t Critical one-tail	2.35	
Standard Error	52.25	21.54
Median	253.90	12.70
Standard Deviation	90.49	48.16
Range	180.70	111.70
Minimum	172.40	9.30
Maximum	353.10	121.00

Since the t stat value is greater than the t critical value and the p-value is less than 0.05 one should reject null hypothesis. At the 0.05 alpha level, the data shows that there is enough evidence to support the claim that the MGBS increased average root growth by dry weight over the Soil W/ Fert. group. According the statistical analysis the roots of the MGBS group grew over 144 grams more on average than the Soil W/ Fert. group even when standard error for both groups is considered. Refer to Figure 26 for the graphical depiction of this data.

3.2.8: Root/Shoot Ratio Analysis

According to the Anderson-Darling test, the data from the MGBS group and Soil W/ Fert. group were Normally Distributed. The test yielded a p-value of 0.082 for the MGBS group and a p-value of 0.256 for the Soil W/ Fert. group. Both of which are greater than significant level alpha of 0.05 therefore one cannot reject the null hypothesis $H_{o.}$

The unpaired right-tailed two sample t-Test was set up as follows:

Null hypothesis (H_o): There is no difference in root/shoot ratio between the groups. H_o: $\mu_1 = \mu_2$

Alternative hypothesis (H_a): The MGBS group had a greater Root/Shoot ratio than the Soil W/ Fert. group. $H_{a:}$ $\mu_1 > \mu_2$

Table 8: Root/Shoot Ratio by Dry Weight Statistical Information

	MGBS	Soil W/ Fert.
Mean	1.36	1.26
Variance	0.24	0.32
Observations	3.00	5.00
Hypothesized Mean Difference	0.00	
df	5.00	
t Stat	0.27	
P(<=t) one-tail	0.40	
t Critical one-tail	2.02	
Standard Error	0.29	0.25
Median	1.62	1.56
Standard Deviation	0.49	0.56
Range	0.88	1.35
Minimum	0.79	0.44
Maximum	1.67	1.79

Since the t stat value is less than the t critical value one should not reject the null hypothesis. The data shows that there is not enough evidence to show that there is a statistical difference in the root/shoot ratio between the groups. The lack of statistical difference between the groups may be due to the small sample size of the study.

3.3: *Pinus nigra* (Austrian Pine)

Out of the 15 pine trees that were planted in this study only three survived the experiment, one in the MGBS group and two in the Soil W/ Fert. group. This means each group experienced an 80% mortality rate. Due to this high mortality rate no statistically significant analysis of the data was possible. The causes of this high mortality rate were not certain but there are a few likely reasons that will be discussed later.

Chapter 4: Discussion

4.1: Answers to Study and Research Questions

1. **What previously untested species can be identified, and will they survive in the gravel beds?**

   As far as the researcher could determine *Pinus nigra* and *Populus nigra x Populus deltoides* had never been tested in the MGBS. Prior to reaching out to Dr. Starbuck and Dr. Johnson a large review was conducted into any MGBS studies that used the above-mentioned tree species.

   Within the gravel beds each species performed very differently with *Populus* hybrid thriving in the hydroponic environment and *Pinus* struggling. It is the researcher's opinion that the irrigation schedule was more conducive to *Populus,* allowing the trees to grow extremely fast in a short period of time. Additionally, unusual weather conditions may have made *Pinus* more susceptible to fungal attack.

2. **Will the species chosen and grown in the MGBS outperform those grown in the soil group?**

Within the *Populus* groups the MGBS trees outperformed the soil control groups considerably. However, given the small sample size and soil variability at the growing sites these results are limited. That being said, a silt loam soil should have been an acceptable soil condition for Populus. The researcher observed mature *Populus deltoides* growing less than 50 feet from the soil plots. Additionally, the soil present on the research site seemed to be alluvial which was further confirmed by the presence of floodplain topography.

The Austrian pine MGBS group was a very different story with only one tree surviving the experiment. In fact, only two trees from the Soil W/ Fert. group survived. The one MGBS tree that did survive did see the highest percent growth however the high mortality rate seemed to be ubiquitous within both groups suggesting potential issues with the site or the bareroot stock themselves. Austrian Pine is considered to be a very hardy tree that is tolerant of many conditions (Shannon, 2015) however it is not without its issues. The most common issues involve blight in some way (Dirr, 2009). Prior to and during the noticeable decline of a majority of the pines in June and July there was a several week stretch of extremely wet, hot, and humid weather. These conditions were prime weather for fungal attack which was observed by Dave Ryan and could have contributed to the high mortality rates.

a. **Will the MGBS have a larger and more robust root system than the soil group?**

According to Figure 25 and Table 6 the *Populus* trees grown in the MGBS grew considerably larger root systems. Although the roots were not cataloged and weighed by size it may have been interesting to see if the MGBS group grew more fine roots than the Soil W/ Fert. group. This researcher suspects that the MGBS group would have seen more fine roots based upon visually observations however this cannot be confirmed. No conclusions can be drawn regarding the Austrian pine root systems due to the high mortality rate in both groups.

b. **Will the MGBS have a higher root/shoot ratio than the soil group?**

Based upon the analysis of the poplar groups no statistically supported answer can be provided for this question. The MGBS group root/shoot average was greater than the Soil W/ Fert. group average, 1.36 vs 1.26, however according to the t-Test there was not enough evidence to say there was a statistical difference between the measured values of the groups. No conclusions can be drawn regarding the root/shoot ratios of the Austrian pine groups because of the previously mentioned high mortality rate within the groups.

3. **What percentage of roots would have been lost if all trees were harvested B&B?**

According to Figure 25 and Table 5 harvesting with a tree spade, typical in the B&B process, could have resulted in a root loss between 67% to 87% of the total root system for the trees that attained a harvestable size. This amount of root loss seems to align with the root loss observed by Fair (2014), Watson and Himelick

(1997), and Magley & Struve (1983). The respective observed root loss values in these studies were 75%, 90%, and 98%. These findings study show the harshness of the B&B process on trees within the nursery industry and the findings of this study continue to support this. As stated previously, this root loss is significant because it can increase establishment periods and cause lasting detrimental impacts on the trees.

4. Does the MGBS have the potential to enhance phytoremediation?

No conclusive answer can be made at this time for this question because this study did not directly study phytoremediation enhancement. However, when looking at the background research cited and the results of this study one can see enough potential to warrant further investigation.

This study showed that the MGBS can increase root growth in *Populus nigra x Populus deltoides* DN 34 verses a silt loam soil condition. Cited sources Labrecque & Teodorescu, 2004 and Zalesny et al., 2007 on *P. nigra x P. deltoides* DN 34 show its ability to remediate many different contaminants while the following cited studies show the significant role that tree roots can play in phytoremediation.

(Aken et al., 2003; Gatliff, 1994; Hollander et al., 2010; Kennen & Kirkwood, 2015; Leigh et al., 2002; Mackova et al., 2006; McCutcheon & Schnoor, 2003; Meggo & Schnoor, 2013; Meharg and Cairney, 2000; Rajakaruna et al., 2006 and Schroder, 2011)

However, *Populus nigra x Populus deltoides* DN 34 was only meant to be a test species due to its fast growth rate. This allowed for a condensed study that would produce enough data to show whether or not the MGBS can increase growth and produce more successful trees in a nursery environment.

4.2: Future Studies and Potential Applications

4.2.1: Sites Prime for Phytoremediation

Research shows that due to the tremendous cost of conventional remediation methods their use on many contaminated sites is not economically feasible especially if contamination levels are low. A large portion of these methods, especially the highly-engineered ones, can cause environmental degradation themselves and could leave remediated soil sterile (Rajakaruna et al., 2006). Some types of sites that have had successful phytoremediation operations include military bases, Department of Defense installations, very large sites, remote locations, landfills, and wastewater treatment plants. With many of these locations the trees were harvested as a cash crop in a coppice system[3] even on some sites with inorganic contamination (Kennen & Kirkwood, 2015). The MGBS could be used to give the phytoremediation coppice species a better start within the contaminated soils if the economics allow for it and the harvested biomass is not a safety concern.

4.2.2: Other Trees to Experiment with the MGBS

During the research process other trees were noticed for their phytoremediation value that could be good MGBS test candidates. Not only have the following trees shown the ability to remediate toxins in the environment but also have coppice capability. For this reason each of

[3] This is a tree production system that involves cutting back hardwood species, to the stump, on a several year rotation to produce large amounts of biomass in a short period of time. The system is very efficient because the above ground portions of the trees are continuously kept in the juvenile stage of their life cycle, extending the life of the trees, while the roots are kept intact with each harvest resulting in highly developed root systems.

these trees have the potential to be doubly productive because on top of being phyto species they are also good sources of timber, high-quality firewood, and other biomass uses.

4.2.2.1: Black Locust (Robinia pseudoacacia)

Black locust would be a significant species to test using the MGBS in a coppice system for many reasons. According to Dirr (2009) *Robinia pseudoacacia* can thrive in a wide range of soil conditions and is easy to transplant. In addition, *R. pseudoacacia* has the ability to fix nitrogen from the air and improve soil fertility. From a phytoremediation perspective black locust has shown the ability to exude compounds that stimulates the growth of contaminant degrading rhizobial microorganisms (Kennen & Kirkwood, 2015).

Locust can be a high value coppice species because of its fast growth rate along with its physical and chemical characteristics. The wood makes excellent lumber because it is one of the strongest and hardest domestic hardwoods that is highly resistant to insect damage and fungal decay (Van Valkenburgh et al., 2011). Seasoned locust wood also makes very high BTU firewood with over 26 million BTU's per cord. This is over 2 million more BTU's than red and white oak (Firewood BTU Ratings, 2016).

4.2.2.2: Osage Orange (Maclura pomifera)

Osage orange is another tough fast growing species that thrives on sites with poor conditions and is readily transplanted (Dirr, 2009). In phytoremediation studies *Maclura pomifera* showed the ability to produce chemicals that stimulate rhizodegradation of PCBs (McCutcheon, 2003). As a lumber the wood is very rot resistant because it contains compounds toxic to fungi (Dirr, 2009). Most impressive however is its energy density with almost 33 million BTU's per cord of firewood (Firewood BTU Ratings, 2016).

Chapter 5: Conclusion

Although superficially successful this experiment was too short and too small to definitively say that the MGBS increases tree growth in nurseries. More studies that are larger in size and longer in duration that test the MGBS against many different soil types will need to be conducted to confirm the results of this study. The duration and size of this study was extremely restricted due to financial and logistical reasons which consequently limited the statistical certainty of the results. For this reason, the researcher relied upon a large amount of background research to support the study and provide a better foundation for future experiments. The results of this study do suggest that the MGBS has the potential to produce more successful trees than soil grown trees. Therefore, due to these potential positive impacts the MGBS might have on tree production additional study is warranted.

To test the MGBS adequately a lot more time and money needs to be invested than what was possible in this study, however as stated many times before one of the main goals of this experiment was to build a foundation for others to build upon. The Neal et al. (2014) study is an excellent example of an experimental setup model that the aforementioned future studies could follow. The Neal et al. (2014) study grew BR stock for three years in which they compared trees grown using typical B&B and containerized processes to trees grown using a new proprietary method. The only modification to this experimental model would be adding a second stage to the study where some of the trees are planted in contaminated soils to see how they perform.

In the statistically significant portions of the experiment, depicted in Figures 19-22 and 24, showed that the MGBS group outperformed the soil group. The dry root growth analysis shown on Figure 26 and Table 6 is perhaps the most significant results of the study. The data from this analysis shows that the BR MGBS trees had over three times more roots than the trees in the silt loam soil group. Furthermore, this root comparison value becomes much greater if the BR MGBS is compared to the B&B process and the root loss that is known to occur during B&B harvest production is considered. Cited background research illuminates the important role tree roots play in plant establishment and the detrimental effects high root losses can have. If future studies into the MGBS system come to similar conclusions as this study, then more tree nurseries may want to try adopting the system in their operations.

Resume:

Thomas J. Frontera II
March 29th, 1990 Beverly, MA

Education:

Masconomet Regional High School — June 2009
Topsfield, MA
High School Diploma

University of Massachusetts at Amherst — May 2013
Amherst, MA
Bachelor of Science in Landscape Architecture

State University of New York College of Environmental Science and Forestry — May 2018
Syracuse, NY
Master of Science in Landscape Architecture

Work Experience:

Renaissance Man Landscaping — April 2008-March 2014
Boxford, Ma
Owner/Founder

Paisley Farm and Greenhouses — May 2012-October 2013
Boxford, MA
Skilled Laborer

Gardens by the Yard — March 2014-November 2014
Wayland, MA
Landscape Designer and Crew Leader

Daniel S. Natchez and Associates — January 2017-Present
Mamaroneck, NY
Lead Project Manager

Bibliography:

Ahern, J. (2011, October). Plants in the Landscape [Personal interview]. Class Lecture

Aken, B. V., Yoon, J. M., & Schnoor, J. L. (2003, September 29). Biodegradation of Nitro-Substituted Explosives 2,4,6-Trinitrotoluene, Hexahydro-1,3,5-Trinitro-1,3,5-Triazine, and Octahydro-1,3,5,7-Tetranitro-1,3,5-Tetrazocine by a Phytosymbiotic Methylobacterium spp. Associated with Poplar Tissues (Populus deltoides nigra DN34). *Applied and Environmental Microbiology*, *70*(1), 508-517.

American Standard for Nursery Stock. (2014). Columbus, OH: AmericanHort. doi:ANSI Z60.1

Anella, L., Hennessey, T., & Lorenzi, E. (2008). Growth of Balled-and-Burlapped Verses Bare-Root Trees in Oklahoma, U.S. *International Society of Arborculture,34*, 200-03.

Anjum, N. A., Pereira, M. E., Ahmad, I., Duarte, A. C., Umar, S., & Khan, N. A. (2013). *Phytotechnologies: Remediation of Environmental Contaminants*. Boca Raton, FL: CRC.

BLACK LOCUST | Black Locust tree | Black Locust Wood. (2000). Retrieved April 10, 2018, from https://www.treeplantation.com/black-locust.html

Boyd, R. B., & Jaffre, T. (2001). Phytoenrichment of soil Ni content by Sebertia acuminata in New Caledonia and the concept of elemental allelopathy. *South African Journal of Science*, 535-538.

"Brownfield Remediation." Green Building Education Services, n.d. Web. 23 Jan. 2017. <http://content.gbes.com/course/leed_ce/ss/bf_453987_20130314/web/>.

Buckstrup, M., & Bassuk, N. (2009). *Creating the Urban Forest: The Bare Root Method*[Pamphlet]. Ithaca, NY: Urban Horticulture Institute, Cornell University.

Buckstrup, M., & Bassuk, N. (2000). Transplanting Success of Balled-and-Burlapped Verses Bare-Root Trees in the Urban Landscape.*Journal of Arboriculture,26.6*.

Capuana, M. (2011). Heavy Metals and Woody Plants - Biotechnologies for Phytoremediation.*Biogeosciences & Forestry*, (4), 7-15.

Chappell, J. (1997). Phytoremediation of TCE Using Populus. US EPA.

Demnerova, K., Stiborova, H., Leigh, M. B., Pieper, D., Pazlarova, J., Brenner, V., Macek, T., Mackova, M. (2003). Bacteria degrading PCBs and CBS isolated from long-term PCB contaminated soil. *Water, Air, and Soil Pollution*, 47-55.

Dietz, A. (2000). *Phytotoxicity of Chlorinated Aliphatics to Hybrid Poplar Cuttings and Axenic Tissue Cultures*. Iowa City, Iowa: The University of Iowa.

Dietz, A., & Schnoor, J. (2001). Advances in Phytoremediation.*Environmental Health Perspectives, 109.1*, 163-68.

Dirr, M. A. (2009). *Manual of Woody Landscape Plants: Their Identification, Ornamental Characteristics, Culture, Propagation and Uses* (6th ed.). Champaign, IL: Stipes Publishing L.L.C.

Doichinova, V., & Velizarova, E. (2013). Reuse of Paper Industry Wastes as Additives in Phytoremediation of Heavy Metals Polluted Substrates from the Spoil Banks of the Kremikovtsi Region, Bulgaria. *Procedia Environmental Sciences,18*, 731-36. Retrieved June 1, 2015.

Ettinger, T. L. (2018, February 25). *Bare Root Plant Materials for Sustainable Landscape Installation*. Lecture.

Fair, B. (2014). Plant Material. Retrieved January 26, 2017, from http://www.ncufc.org/plant-material.php

Firewood BTU Ratings. (2016). World Forest Industries. Retrieved April 10, 2018, from http://worldforestindustries.com/forest-biofuel/firewood/firewood-btu-ratings/

Gatliff, E. (1994). Vegetative Remediation Process Offers Advantages over Traditional Pump-and-Treat Technologies. *Remediation*.

Gilman, E. F., & Beeson, R. C., Jr. (1996, June). Nursery production method affects root growth. *Journal of Environmental Horticulture,14*(2), 88-90.

Gomes, H. I., Dias-Ferreira, C., & Ribeiro, A. B. (2012, November 28). Overview of in situ and ex situ remediation technologies for PCB-contaminated soils and sediments and obstacles for full-scale application. *Science of the Total Environment*, 237-260.

Halka, C., Jr. (2017). Our 12 Step Process. Retrieved March 20, 2018, from https://www.halkanursery.com/our-process/

Haug, M.C. (1996). Increasing transplant success of bare-root trees by minimizing water stress during handling. Cornell University, Ithaca, NY, MS Thesis.

Harris, R. W. (1992, January). Root-Shoot Ratios. *Journal of Arboriculture,18*(1), 39-42.

Hollander, J., Kirkwood, N., & Gold, J. (2010). *Principles of Brownfield Regeneration: Cleanup, Design, and Reused of Derelict Land* (pp. 31-35). Washington: Island.

Hong, M., Farmayan, W., Dortch, I., Chiang, C., Mcmillan, S., & Schnoor, J. (2001). Phytoremediation of MTBE from a Groundwater Plume. *Environmental Science and Technology,35.6*, 1231-39.

Hutnik, R., McClenahen, J., Long, R., & Davis, D. (2014). Mercury Accumulation in Pinus Nigra. *Northeastern Naturalist,21.4*, 529-38.

Johnson, G. (2015, April 15). Missouri Gravel Bed System [E-mail interview].

Kennen, K., & Kirkwood, N. (2015). *Phyto: Principles and Resources for Site Remediation and Landscape Design*. London: Routledge; Taylor & Francis Group.

Labrecque, M., & Teodorescu, T. I. (2004, December 15). Field performance and biomass production of 12 willow and poplar clones in short-rotation coppice in southern Quebec (Canada). *Biomass and Bioenergy*, 1-9.

Landmeyer, J. (2012). *Introduction to Phytoremediation of Contaminated Groundwater: Historical Foundation, Hydrologic Control, and Contaminant Remediation*. Dordrecht: Springer.

Leigh, M. B., Fletcher, J. S., Fu, X., & Schmitz, F. J. (2002). Root Turnover: An Important Source of Microbial Substrates in Rhizosphere Remediation of Recalcitrant Contaminants. *Environmental Science & Technology Journal, 36*(7), 1579-1583.

Leigh, M., Mackova, M., Nagle, D., & Fletcher, J. (2006). Polychlorinated Biphenyl (PCB)-Degrading Bacteria Associated with Trees in a PCB-Contaminated Site. *Applied and Environmental Microbiology,72.4*, 2331-342. Retrieved June 15, 2015.

Leigh, M., Pellizari, V., Uhlik, O., Sutka, R., Rodrigues, J., Ostrom, N., Zhou, J., Tiedje, J. (2007). Biphenyl-utilizing bacteria and their functional genes in a pine root zone contaminated with polychlorinated biphenyls (PCBs). *The International Society of Microbial Ecology Journal,1*, 134-148.

Liebhold, A. M., Brockerhoff, E. G., Garrett, L. J., Parke, J. L., & Britton, K. O. (2012). Live plant imports: The major pathway for forest insect and pathogen invasions of the US. *Frontiers in Ecology and the Environment,10*(0), 135-143. doi:10.1890/110198

Mackova, M., Dowling, D., & Macek, T. (2006). *Phytoremediation and Rhizoremediation: Theoretical Background* (Vol. 9A). Dordrecht: Springer.

Magley, S. B., & Struve, D. K. (1983). Effects of three transplant methods on survival, growth and root regeneration of caliper pin oaks [Quercus palustris]. *Journal of Environmental Horticulture*.

McCutcheon, S., & Schnoor, J. (2003). *Phytoremediation: Transformation and Control of Contaminants*. Hoboken: Wiley-Interscience.

Meggo, R. E., & Schnoor, J. L. (2013, April 6). Rhizosphere redox cycling and implications for rhizosphere biotransformation of selected polychlorinated biphenyl (PCB) congeners. *Ecological Engineering,* 285-292.

Neal, C., Papineau, A., Lass, D., & Wei, H. (2014). *Growth and Root Characteristics of Trees in Three Northern Nursery Production Systems* (Poster). USDA-NIFA.

Newman, L., & Reynolds, C. (2005). Bacteria and Phytoremediation: New uses for endophytic bacteria in plants. *Trends in Biotechnology,23*(1), 6-7. Retrieved July 1, 2015, from www.sciencedirect.com

Populus deltoides x Populus nigra. (n.d.). Retrieved December 3, 2015, from http://www.advancedtree.com/Tree-Hybrid-Poplar.aspx

US EPA. (2010). *Phytotechnologies for Site Cleanup*. 1-2, 6-7.

Rai, M., & Varma, A. (2011). *Diversity and Biotechnology of Ectomycorrhizae* (Vol. 25). Heidelberg: Springer.

Rajakaruna, N., Tompkins, K. M., & Pavicevic, P. G. (2006). Phytoremediation: An affordable green technology for the clean-up of metal-contaminated sites in Sri Lanka. *Ceylon Journal of Science (Biological Sciences), 35(*1*), 25-39*.

Randall, T. (Director). (2013). *Ground Zero Supertower* [Video file]. United States: Terri Randall Productions. Retrieved March 15, 2018, from https://www.netflix.com/title/80003181

Ryan, D., & Ryan, J. (n.d.). Missouri Gravel Bed System. Retrieved April 10, 2015, from http://www.rareearthnursery.net/gravelbed.html

Schroder, P., & Collins, C. (2011). *Organic Xenobiotics and Plants: From Mode of Action to Ecophysiology* (Vol. 8). Dordrecht: Springer.

Shannon, S. (2015, September 28). Plant ID [Personal interview].

Singh, H. (2006). *Mycoremediation: Fungal Bioremediation*. Hoboken, New Jersey: Wiley-Interscience.

Spriggs, T., Banks, K., & Schwab, P. (2005). Phytoremediation of Polycyclic Aromatic Hydrocarbons in Manufactured Gas Plant-Impacted Soil. *Journal of Environmental Quality,34*, 1755-62.

Starbuck, D., Struve, D., & Mathers, H. (2005). Bareroot and Balled-and-Burlapped Red Oak and Green Ash Can Be Summer Transplanted Using the Missouri Gravel Bed System. *Hort Technology,* 122-27.

Starbuck, C. (2015, April 15). Missouri Gravel Bed System [E-mail interview].

The Journey of a Bare Root Tree [Video file]. (2015, December 17). In *The Journey of a Bare Root Tree*. Retrieved October 20, 2016, from http://www.groworganic.com/organic-gardening/videos/the-journey-of-a-bare-root-tree

Urban, J. R. (2011, June). The Bare-Root Cause: Bare-root planting is a better choice for tree health. *Landscape Architecture Magazine*, 54-58.

Van Valkenburgh, M., Noone, S., Zoli, T., & Lavender, D. (2011). *Black Locust Lumber: A Sustainable Alternative*(Rep.). San Diego, CA.

Watson, G. W., and E.B. Himelick. (1997). Principles and Practice of Planting Trees and Shrubs. *International Society of Arboriculture*, Champaign, IL. 199.

Watson, G. W. (1986). Cultural Practices Can Influence Root Development for Better Transplanting Success. *The Journal of Environmental Horticulture,4*(1), 32-34.

Watson, G. W. (1982, September). Root distribution of nursery trees and its relationship to transplanting success. *Journal of Arboriculture,8*(9), 225-229.

Watson, G. (1985, February). Tree size affects root regeneration and top growth after transplanting. *Journal of Arboriculture,11*(2), 37-40.

Whitcomb, C. (2014, April 28). Improving Plant Root Systems. Lecture presented at JCCC Inaugural Horticultural Sciences Day in Johnson County Community College, Overland Park, Kansas. Retrieved March 12, 2018, from www.jccc.edu.

Yifru, D. D., & Nxengung, V. A. (2006, July 28). Uptake of N-Nitrosodimethylamine (NDMA) from Water by Phreatophytes in the Absence and Presence of Perchlorate as a Co-Contaminant†. *Environmental Science and Technology*, *40*(23), 7374-7380.

Zalesny Jr., R., & Bauer, E. (2007). Evaluation of Populus and Salix Continuously Irrigated with Landfill Leachate I. Genotype-Specific Elemental Phytoremediation. *International Journal of Phytoremediation,8*, 281-306.

Zalesny, R. S., Jr., Wiese, A. H., Bauer, E. O., & Riemenschneider, D. E. (2009). Ex situ growth and biomass of Populus bioenergy crops irrigated and fertilized with land fill leachate. *Biomass and Bioenergy*, 62-69.